Tectonophysics

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Modelling the formation of stylolites

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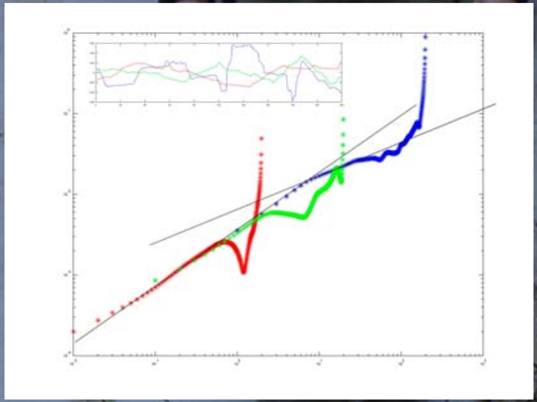
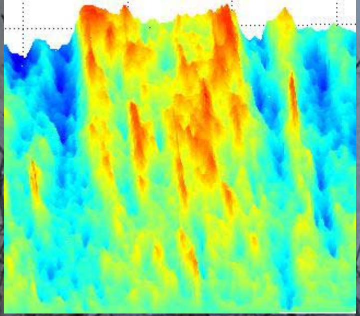
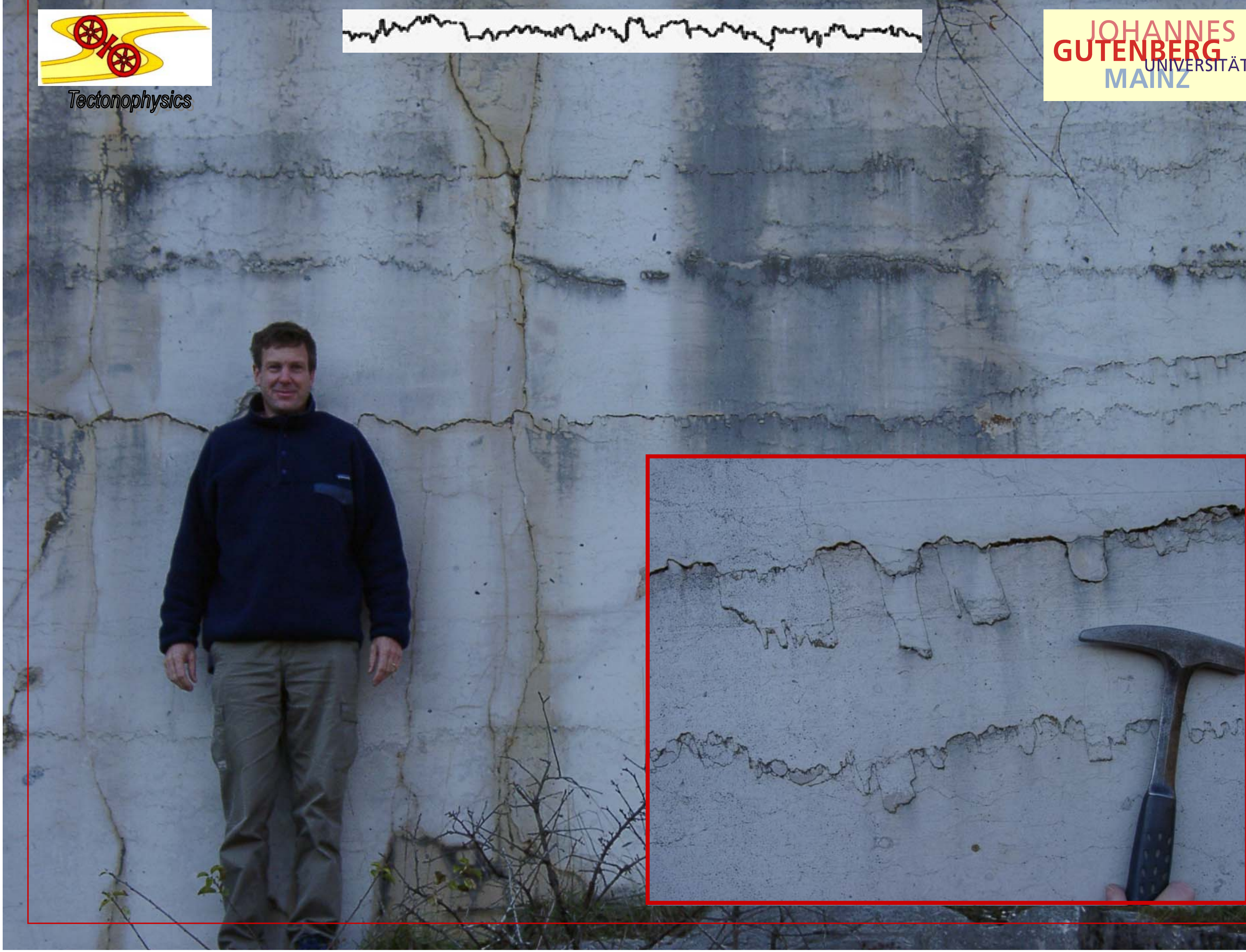
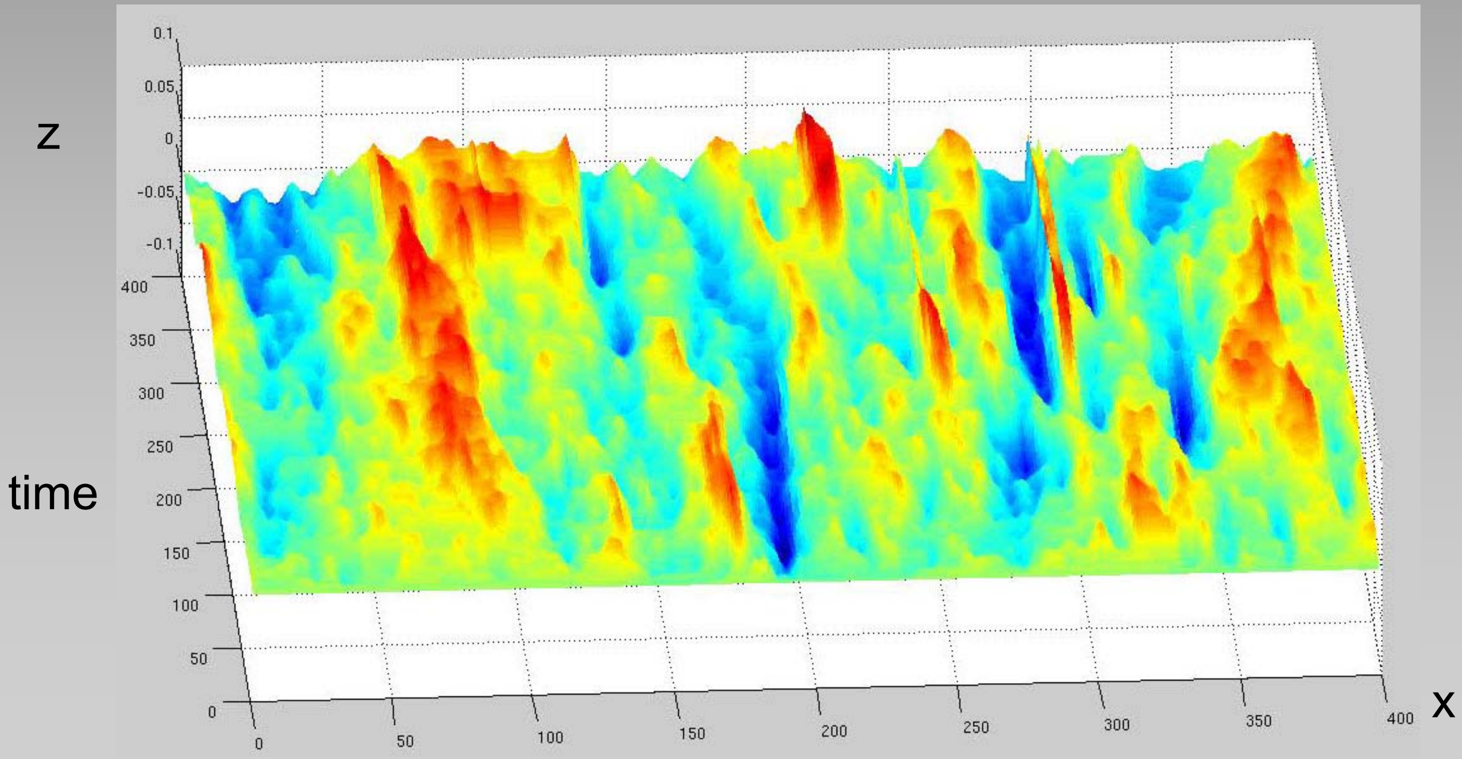




Natural examples



Numerical Model



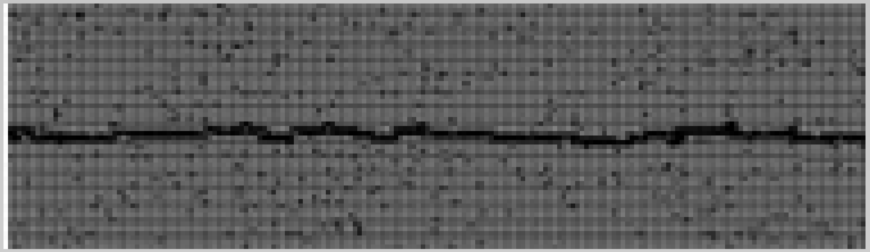
Equation for dissolution of the surface

$$D_r = k_r V_s \left(1 - \exp\left(-\frac{\Delta\sigma_n V_s + \Delta\psi_s}{RT} \right) \right)$$

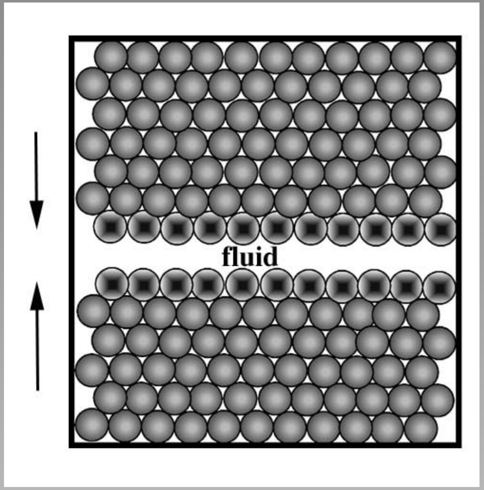
Surface energy -> curvature of interface

Elastic energy and normal stress at interface -> determined using a linear elastic lattice Spring model.

Quenched noise in dissolution constants



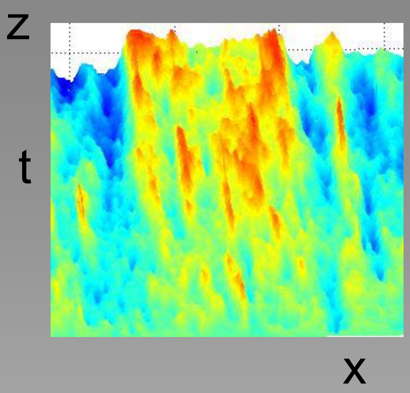
Setup for the simulations



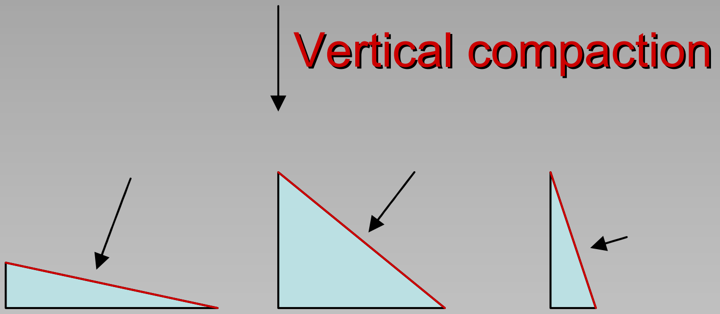
Two solids are compressed vertically. Dissolution only occurs at the interface. Side walls are fixed. Constant strain rate (applied in small steps).

Elastic and surface energy promote a flat surface
Normal stress is the same on both sides of the surface

Noise drives the roughening !



Why teeth ?

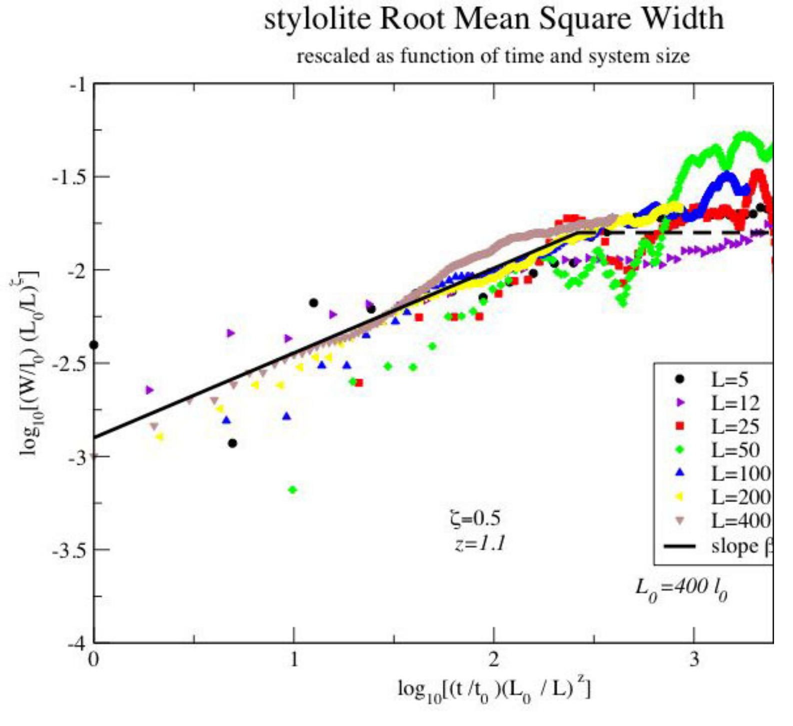


The side walls of teeth do not move when they are oriented verticallly (in a horizontal stylolite) unless one side of the surface is growing.

Animation: voir fichier teeth.mov

Animation: voir fichier fourh.mov

Scaling


stylolite Root Mean Square Width
rescaled as function of time and system size
$\log_{10}[(W/l_0)(L_0/L)^{\zeta}]$
$\log_{10}[(t/t_0)(L_0/L)^{z}]$
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
1
2
3
L=5
L=12
L=25
L=50
L=100
L=200
L=400
slope β
ζ=0.5
z=1.1
$L_0=400\ l_0$

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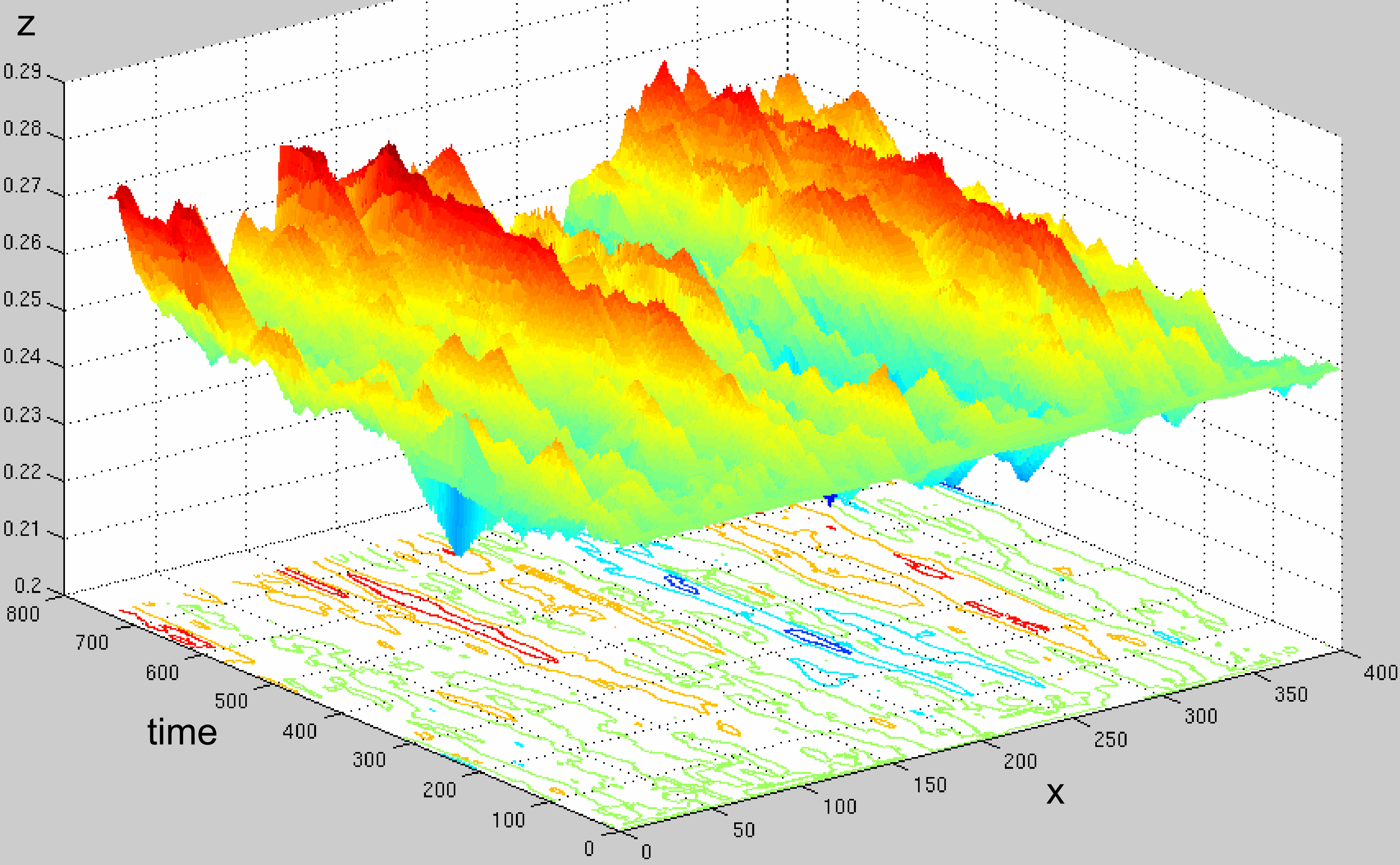
Scaling in time and space -> dynamic scaling law



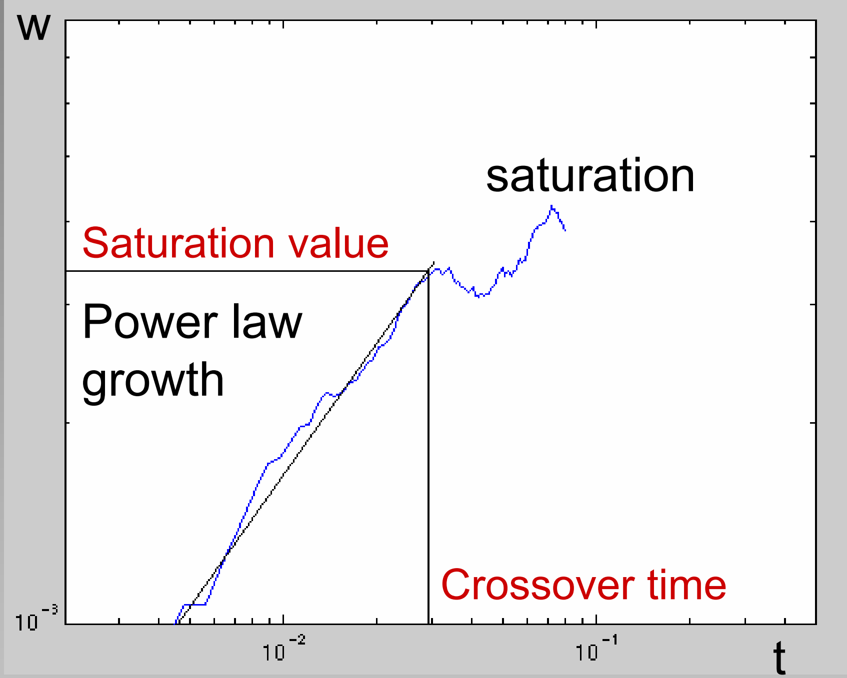
Family-Vicsek Scaling

Interface width (characterizes roughness) is measured as *rms* fluctuation in height

Width plotted against time gives two scaling regimes separated by a crossover time

Initially the width increases as a power of time

$$\boxed{w(L,t) \sim t^{\beta}}$$



β is the growth exponent and characterizes the time-dependent dynamics of the roughening process

Saturation value scales as $\boxed{w_{sat}(L) \sim L^{\alpha}}$

Crossover time scales as $\boxed{t_x \sim L^{z}}$

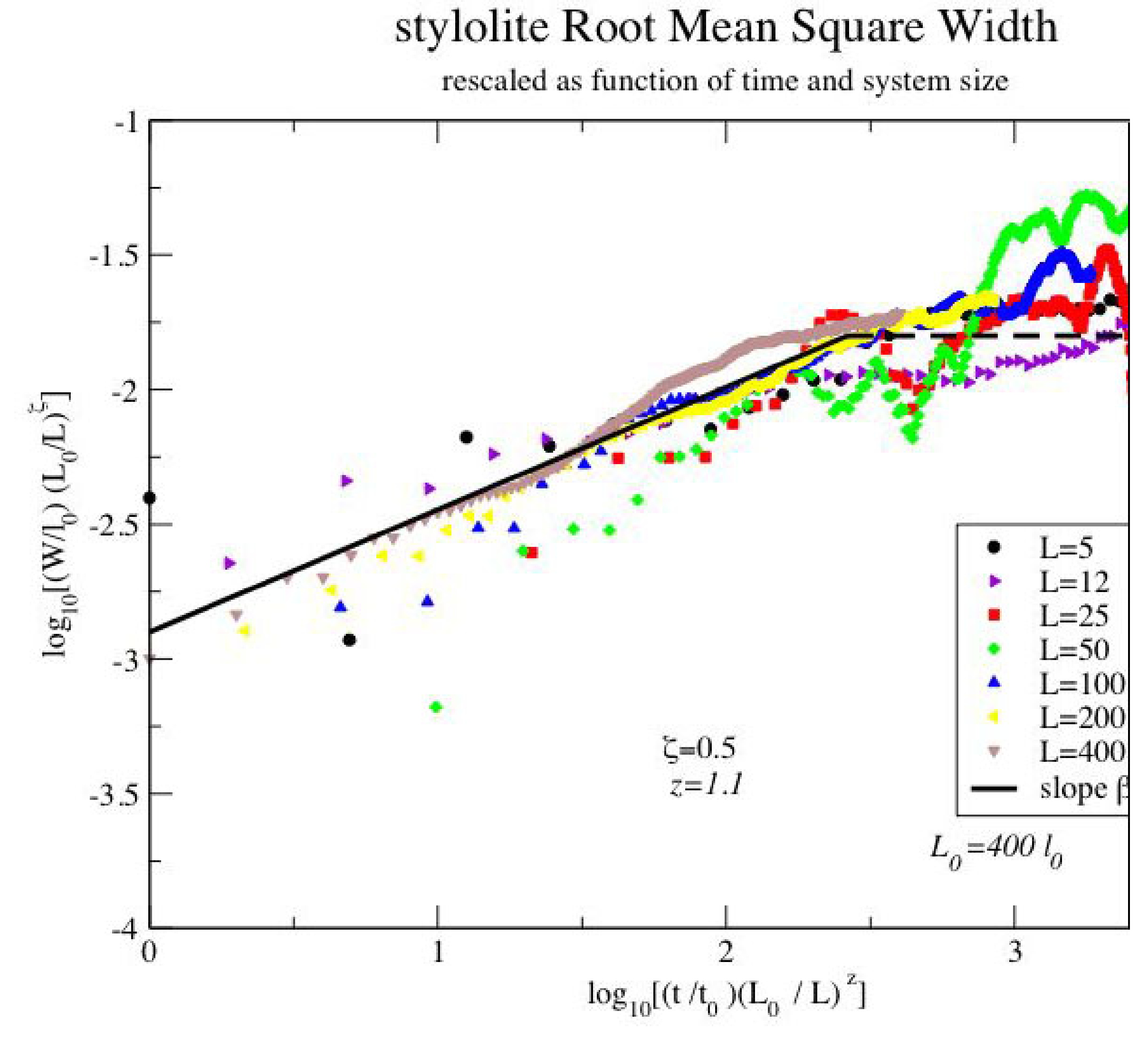
Where L is the system size

Barabási and Stanley, 1995

Family Vicsek scaling works !

The growth exponent beta lies around 0.46, the roughness exponent alpha or zeta is 0.5 and the dynamic exponent is 1.1

This gives us a dynamic scaling law for the simulations !



Animation: voir fichier fourg.mov

Animation: voir fichier teeth.mov

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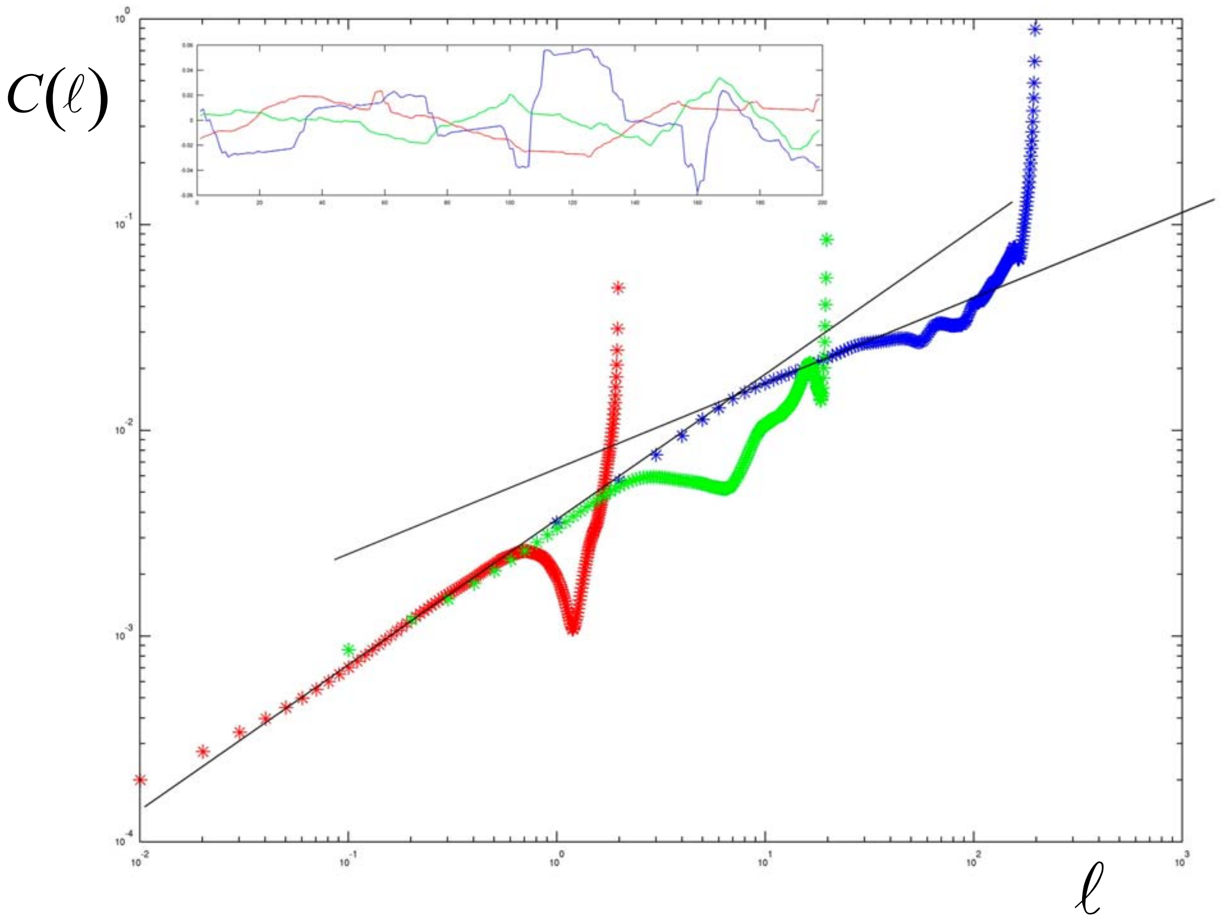
height-height correlation function

$$C(\ell) \equiv \left[\left\langle \left(h(x) - h(x')\right)^2 \right\rangle_x \right]^{1/2}$$

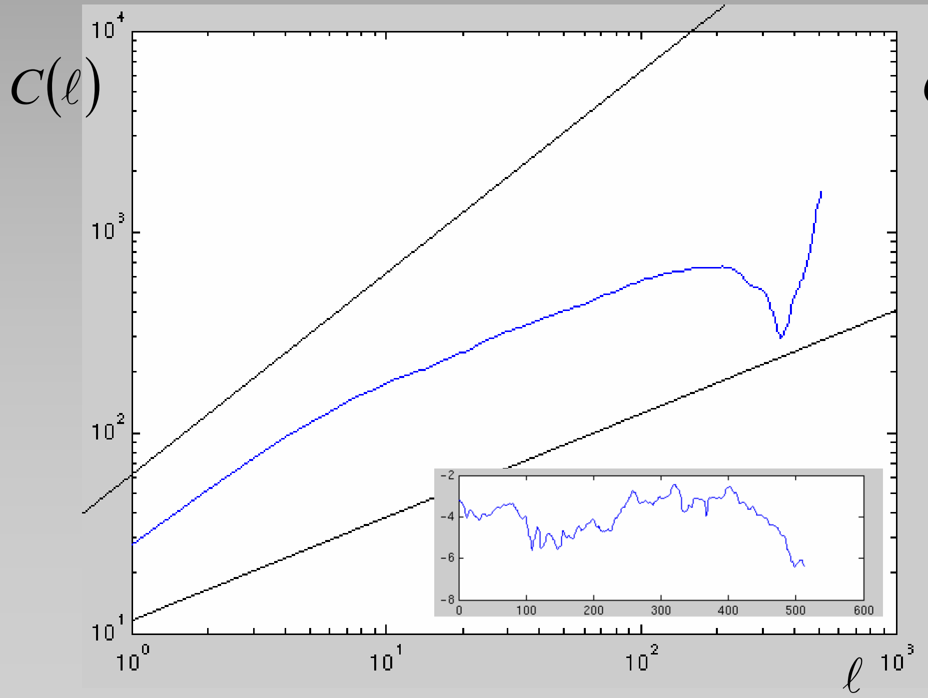
$$\left[|x - x'| = \ell \right]$$



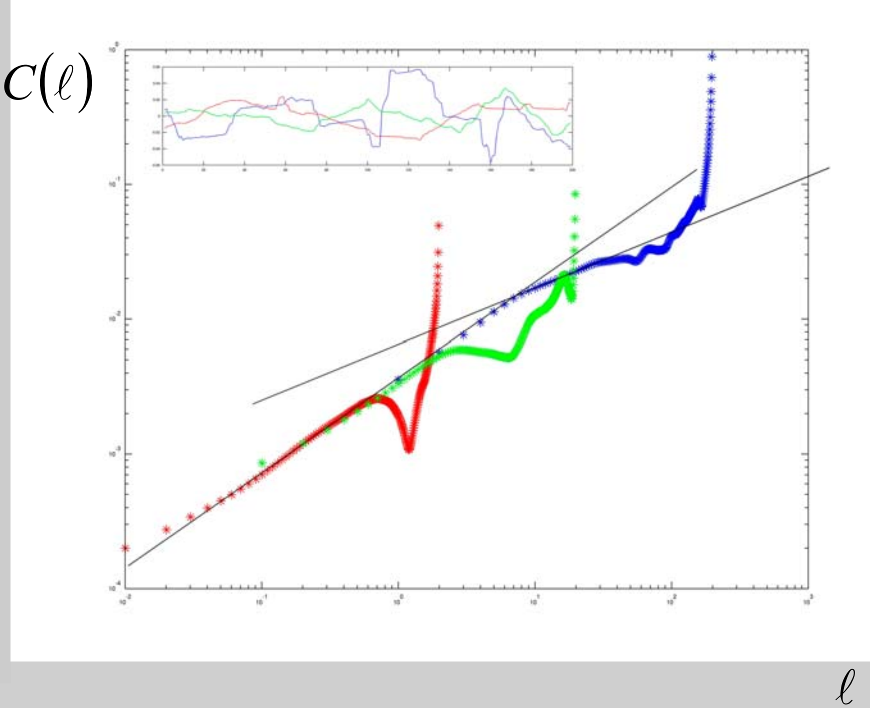
Two regimes: surface energy dominated and elastic energy dominated !

Both regimes show self affine scaling

Nature



Simulations

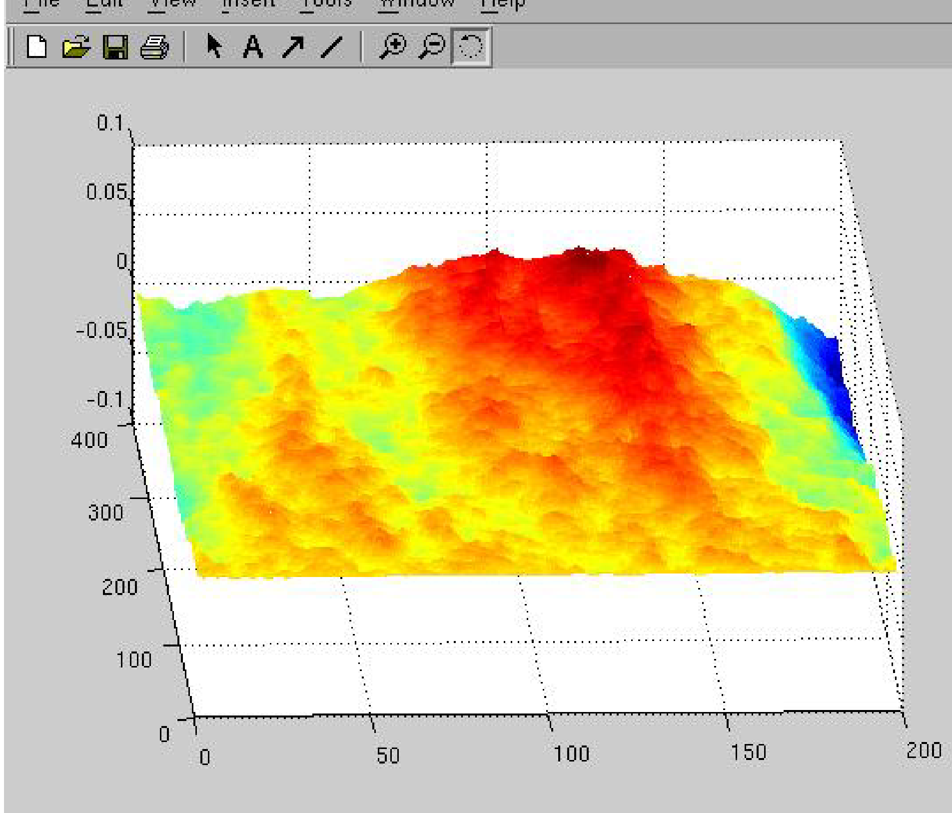


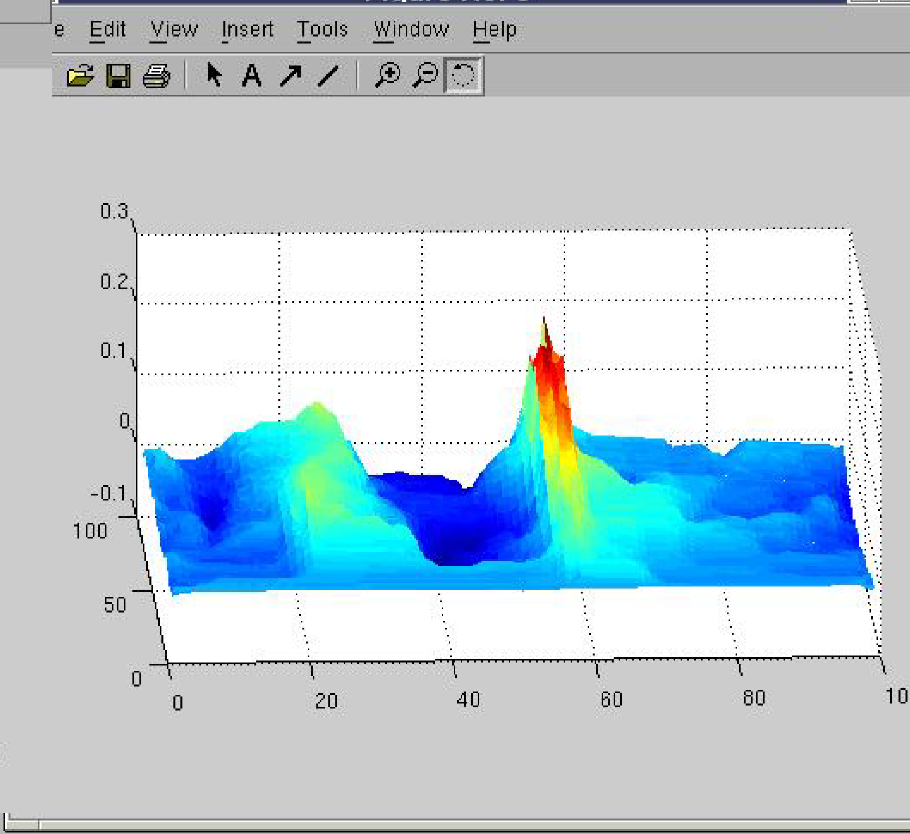
Conclusions:

- We present a dynamic scaling law for stylolites
- The development of teeth in stylolites is a normal consequence of the compaction that creates the stylolite in the first place
- We can reproduce the two different scaling regimes of Schmittbuhl et al. (2004).
- Therefore stylolites scale with a high roughness exponent within the surface energy dominated regime
- They show a crossover
- They scale with a low roughness exponent within the elastic energy dominated regime.
- Stylolite growth decays with time ! Therefore the amplitude of a stylolite is not representative for the compaction !

Need to explore how crossover is shifted when conditions change (stress, noise)

Need to analyse more natural examples !


0.1
0.05
0
-0.05
-0.1
400
300
200
100
0
0
50
100
150
200


Edit
View
Insert
Tools
Window
Help
0.3
0.2
0.1
0
-0.1
100
50
0
0
20
40
60
80
10

The development of mechanical instabilities during stress corrosion

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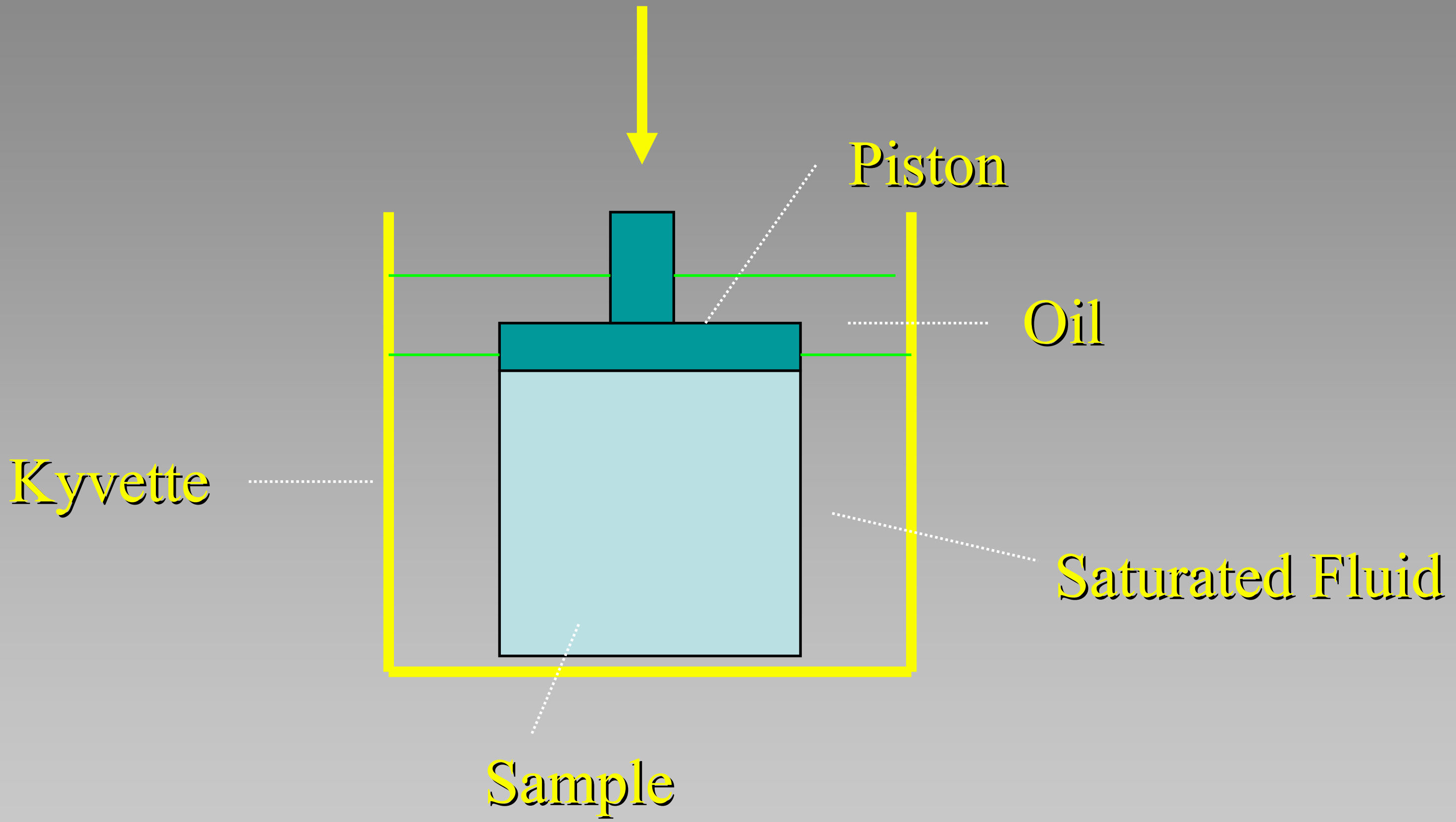
Anders Malthe-Sørenssen, Dag C. Dysthe, Bjørn Jamtveit, Jochen Arnold

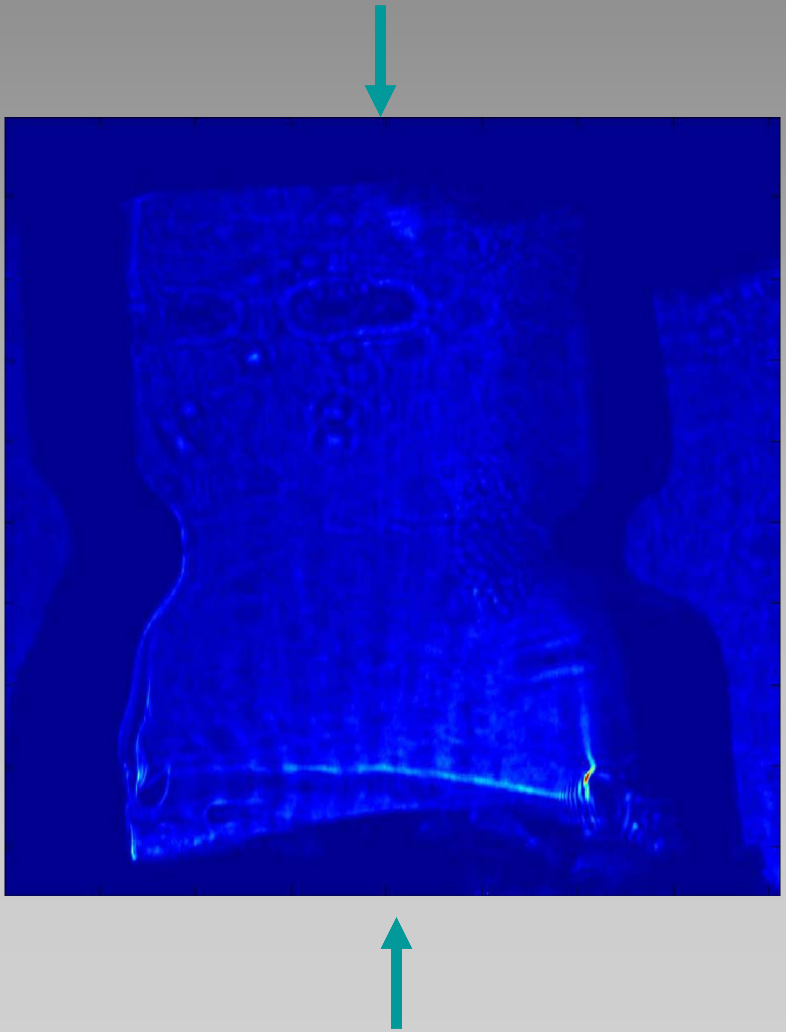
Experimental Setup



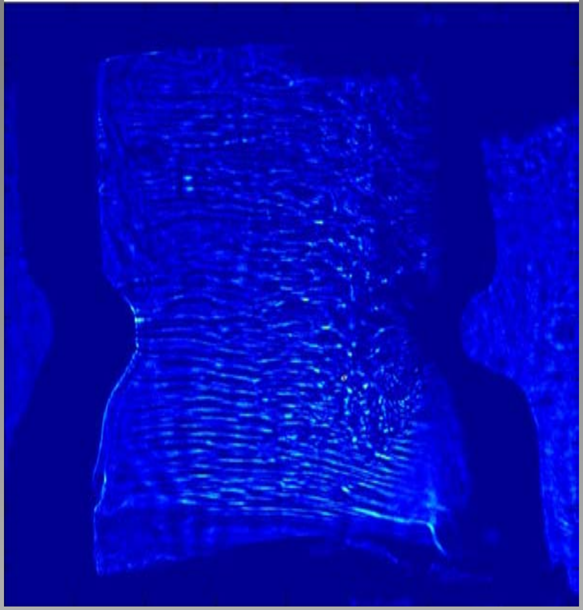
3 step Temperature control, In situ observation

$NaClO_3$ crystal in saturated solution

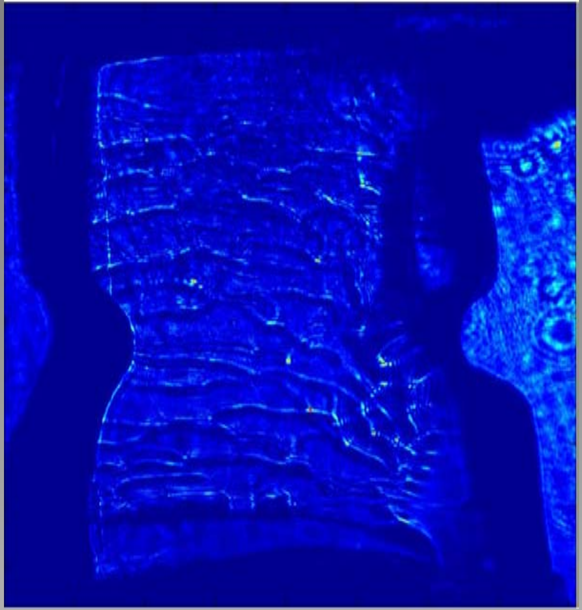
height 3mm
room temperature



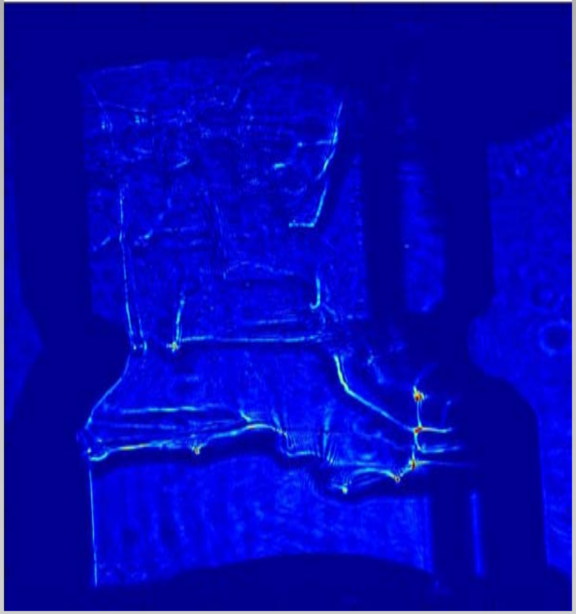
Animation: voir fichier rough4.mov



initial
roughness

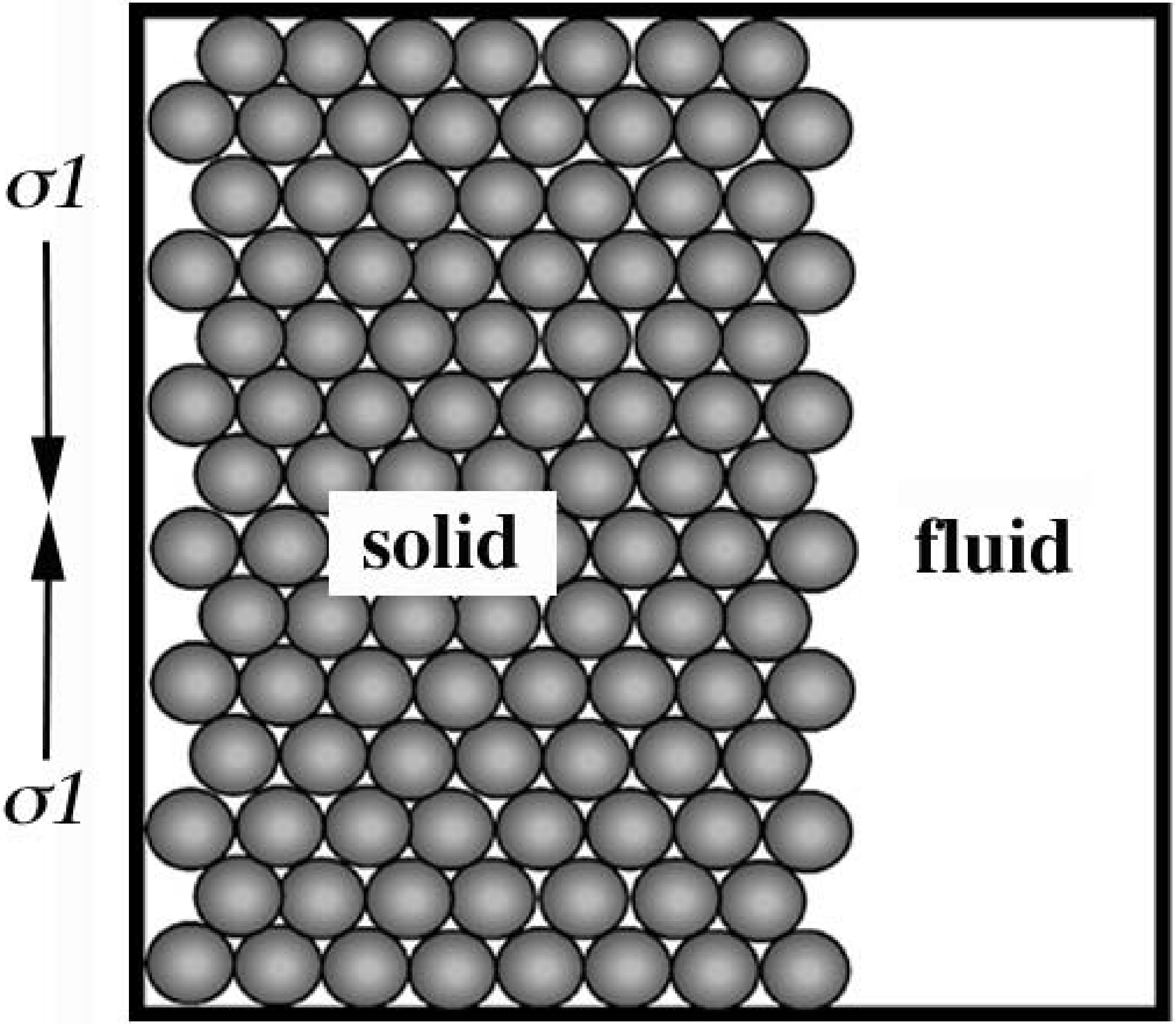


coarsening



super-
structure

phase-
transition


σ1
σ1
solid
fluid

fluid

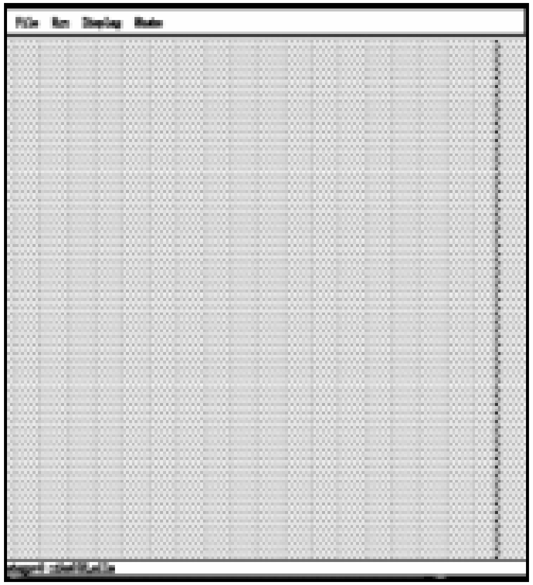
Animation: voir fichier 3.5.MOV

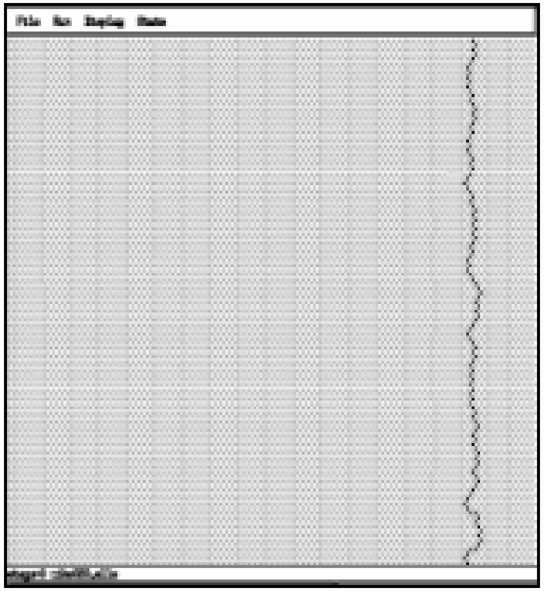
fluid

Animation: voir fichier 3.87.MOV

fluid

Animation: voir fichier 3.67.mov


File Run Display Mode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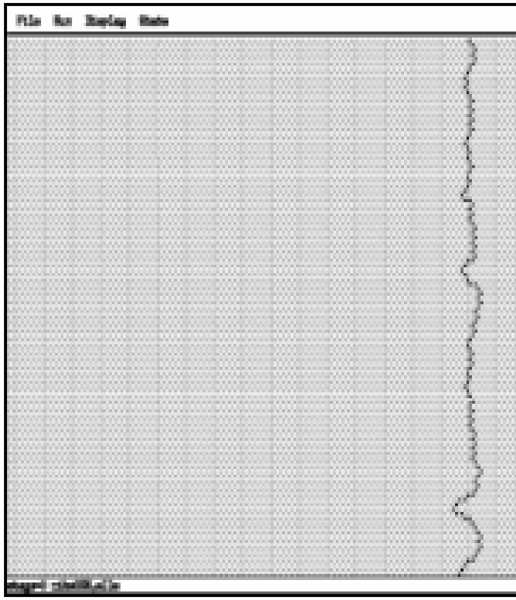
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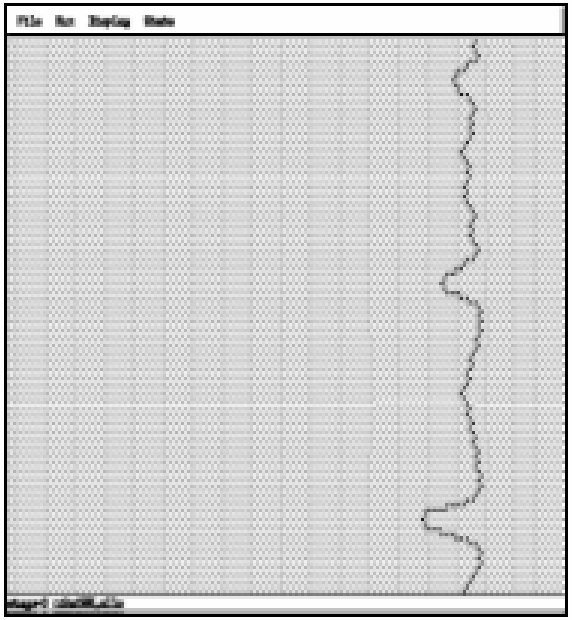
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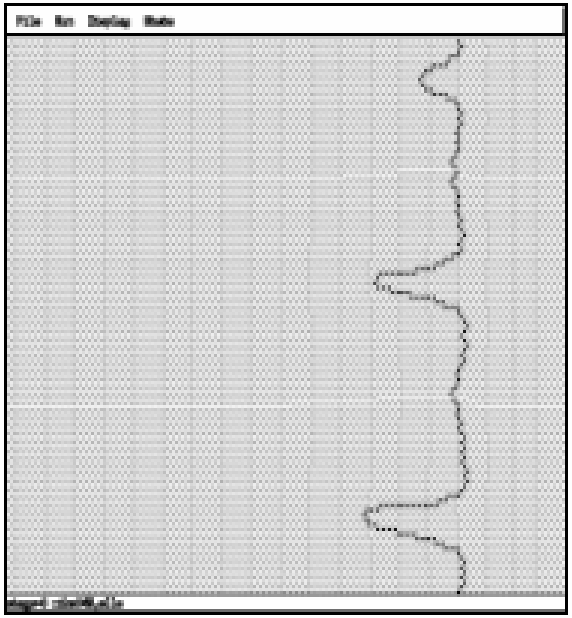
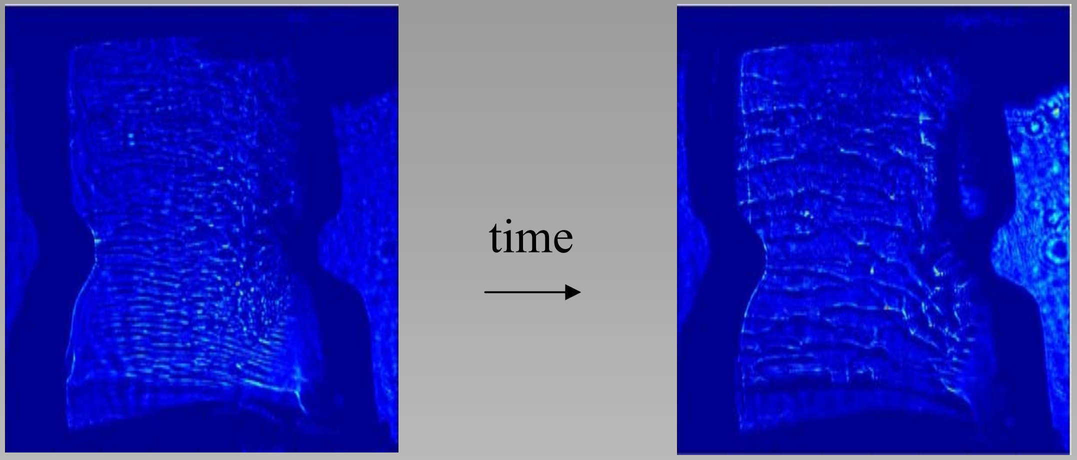

File Run Display Mode

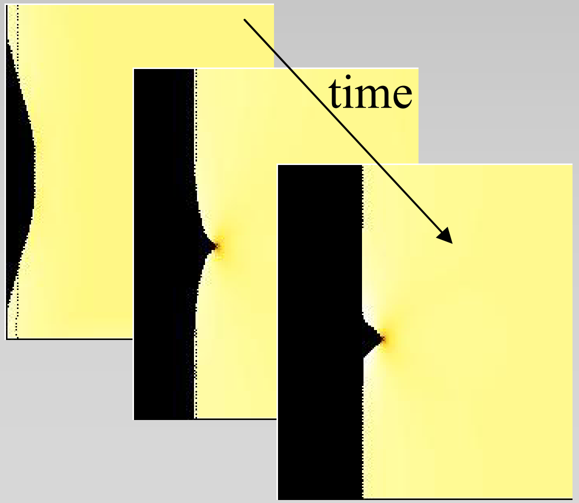
Competition between elastic and surface energy plus effects of stress shielding

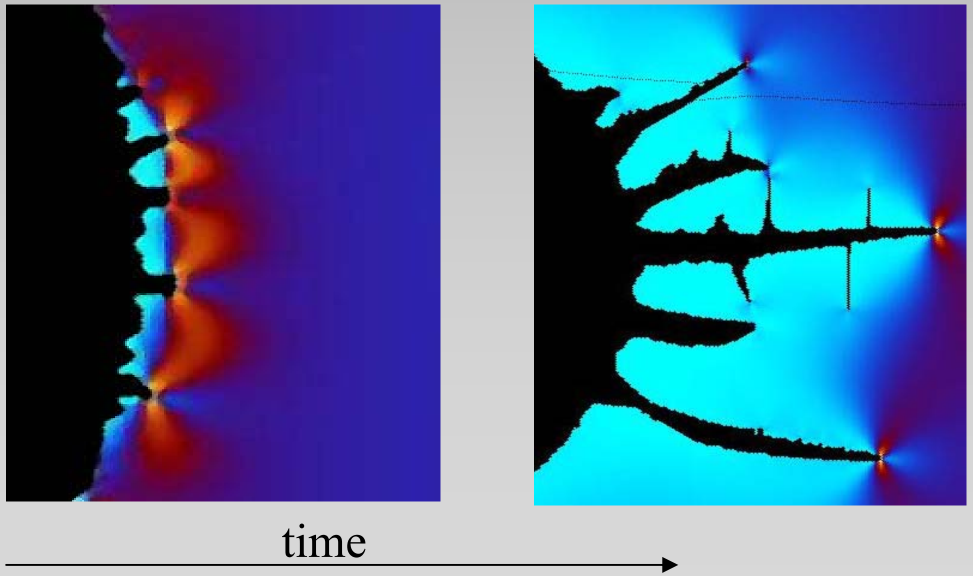
Experiment



roughness → coarsening

Simulation

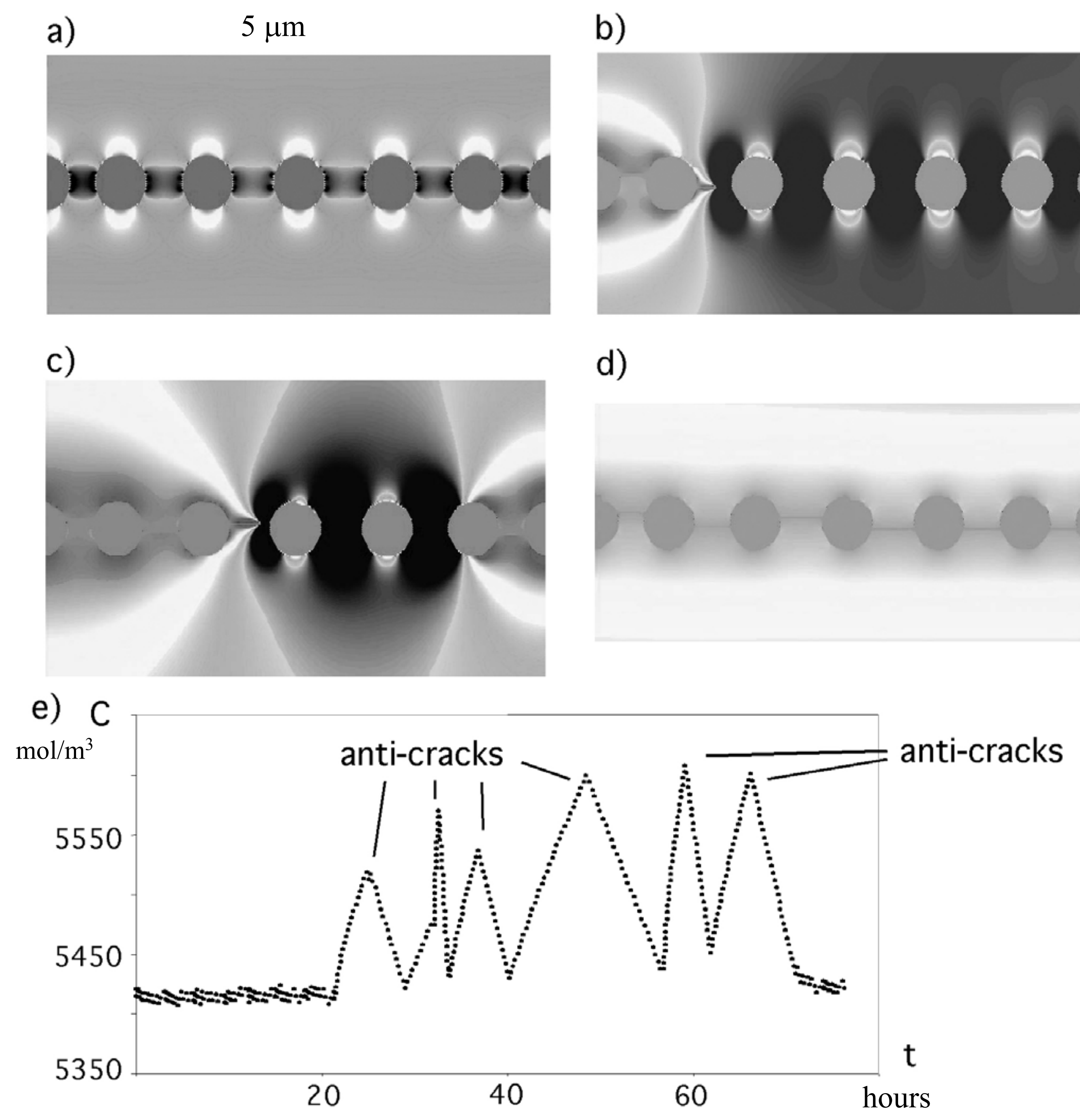




Numerical simulations of the development of roughness in confined interfaces

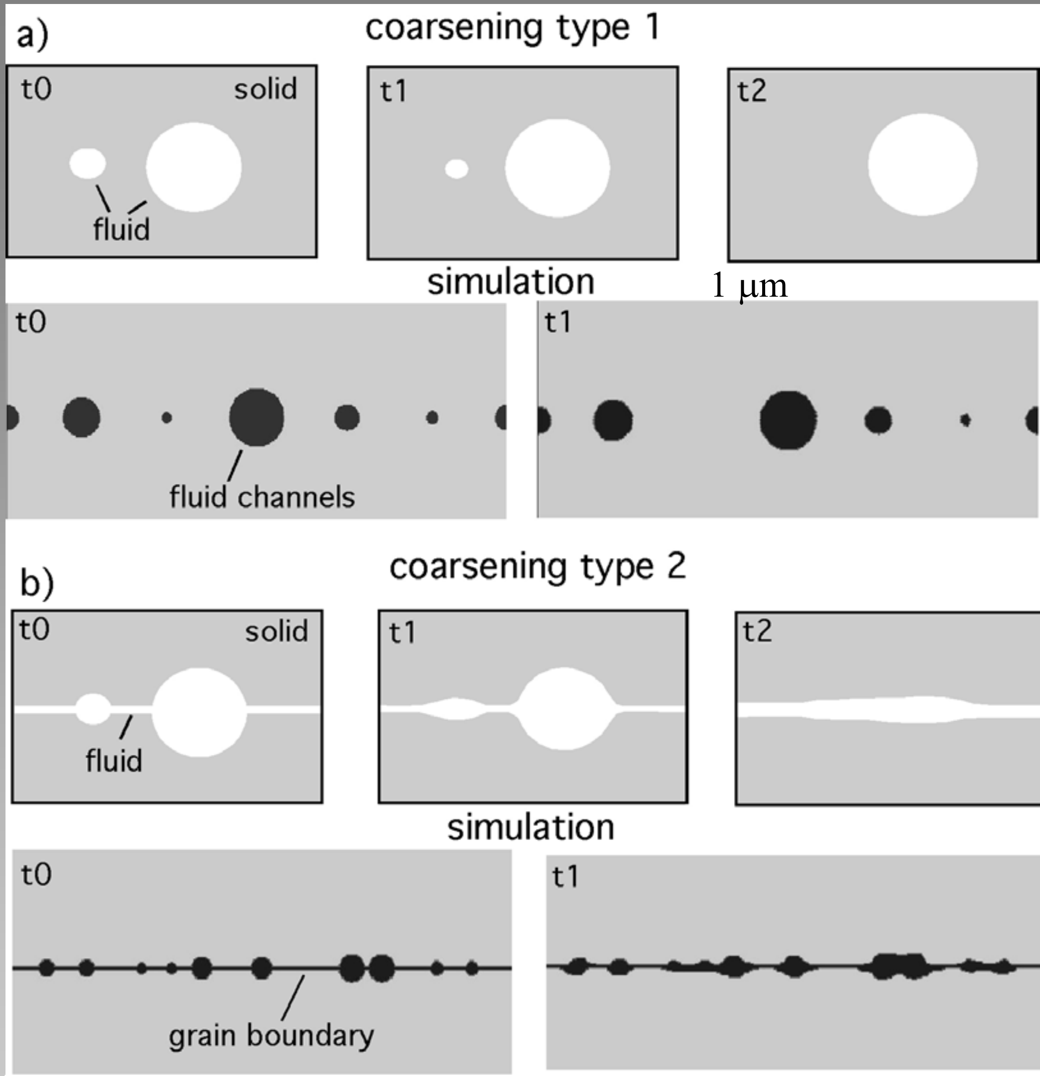
Solid islands are not very stable ! They are destroyed by undercutting / anticracking

-> concentrations of elastic energy



Surface energy in a grain boundary with solid islands will lead to „channel-growth“

Surface energy in a rough grain boundary with fluid within the whole contact leads to a smoothening of the structure



Roughening plus surface energy effects produce island-channel structure that coarsens with time !

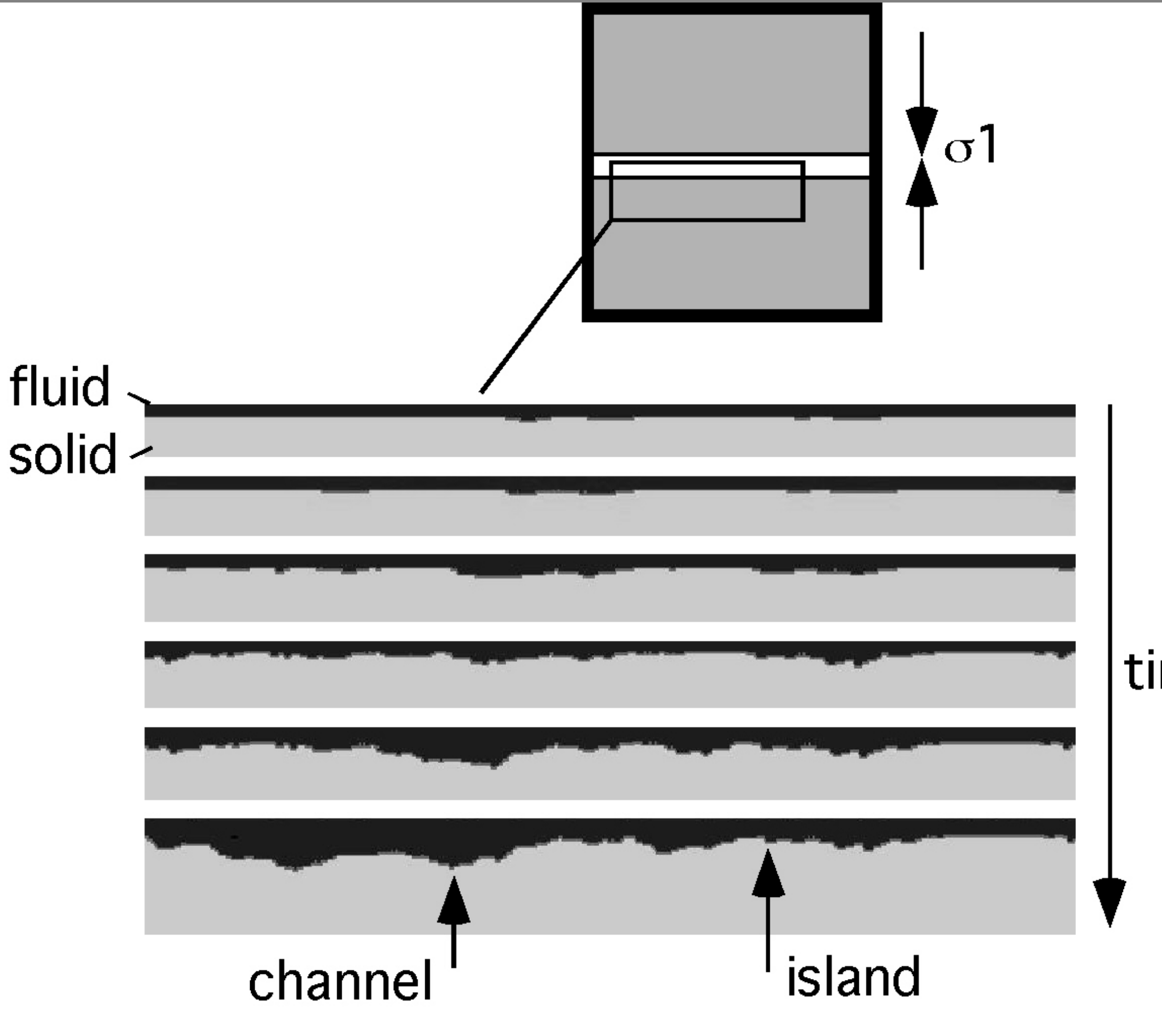


Fig. 7